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Short Communication

Mapping the Impact of Transdisciplinary Research: A Visual Comparison of Investigator-Initiated and Team-Based Tobacco Use Research Publications

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Abstract

Science is increasingly being carried out in large cross-disciplinary research teams. However, currently little empirical research focused on understanding the outcomes and added-value associated with this type of research approach exists. This study utilizes a scientific mapping technique to compare the structure and topical coverage of publications over time for a transdisciplinary center-based initiative with a matched set of traditional investigator-initiated grants in the same field. Publication data obtained from two National Institutes of Health (NIH) databases for all three groups were overlaid onto the University of California, San Diego (UCSD) Base Map of Science. The visualizations revealed that the publications from the transdisciplinary research centers spread across the topic map of science more rapidly and more comprehensively than both comparison groups. These findings are consistent with the notion that bringing scientists together from multiple disciplines can lead to more rapid proliferation and dissemination of scholarly knowledge across the scientific spectrum, thereby increasing the speed of scientific discovery and innovation.

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ABBREVIATIONS

TTURC: Transdisciplinary Tobacco Use Research Centers; NIH: National Institutes of Health; NCI: National Cancer Institute

INTRODUCTION

The proliferation of, and increasing access to, scholarly knowledge (i.e. data deluge), coupled with the complexity of many intractable public health problems, have prompted increasing interest and investment in team-based research in areas such as tobacco control, obesity, health disparities and health communications [1-9]. Many of these initiatives place a strong emphasis on cross-disciplinary approaches and more specifically, transdisciplinary collaboration, which leverages the strengths and perspectives of multiple disciplines to accelerate the production of scholarly knowledge and the translation of scientific findings into novel health practices and policies [10].

Cross-disciplinary research can be conceptualized along a continuum of integration with *multidisciplinary collaboration* falling at one end of the spectrum, and *transdisciplinary collaboration* at the other with *interdisciplinary collaboration* falling in between [11,12]. Multidisciplinary and interdisciplinary research collaborations combine the perspectives and methods from multiple disciplines in an effort to create a more holistic and complex research approach, though participants largely remain anchored in team members' respective disciplines. By contrast, in transdisciplinary research, participants transcend their disciplinary boundaries and engage in a collaborative process to develop new shared conceptual frameworks and methodological approaches that integrate and ultimately extend beyond their individual disciplinary perspectives [13,14].

There is some evidence to suggest that a transdisciplinary research center-based approach leads to greater productivity and increased collaboration compared to traditional investigator-initiated research grants (e.g., R01; [4]). However, the impact of these publications and the ways in which they influence the broader scientific landscape remains unclear. Given the tremendous investment in time and resources required to launch and implement a large center-grant initiative, it is important to understand the scholarly impact and added-value associated with funding this particular type of research endeavor.

Micro-level data (e.g. at the individual level) in combination with innovative data analysis and visualization techniques such as science mapping can be used to increase our understanding of the structure and evolution of scientific knowledge and collaboration [15]. For example, science mapping techniques have been used to examine the influence of grants on the number and citations counts of research papers [16] as well as illustrate feedback cycles that trace industry and federal government support for innovation through various phases of the research process [17].

The present study utilizes this scientific mapping approach in a novel way to compare the broad scientific impact of large-scale transdisciplinary center funding with more traditional smaller-scale investigator-initiated research funding. Specifically, we examine the evolving topical coverage and spread of publications from the Transdisciplinary Tobacco Use Research Centers (TTURCs; [18]), a ten-year transdisciplinary center grant initiative funded through the National Cancer Institute (NCI) to support tobacco control research, with two sets of matched investigator-initiated R01grants covering the same timeframe and the same area of research [4].

MATERIALS AND METHODS

Sample

The data used in this quasi-experimental study design comprises one target group (TTURCs) and two comparison groups. The target group includes six TTURC centers that received continuous funding from 1999-2009. These centers supported 39 distinct primary research subprojects that lasted for either 5 (N= 33) or 10 (N=6) years. The second and third comparison groups consist of investigator-initiated tobacco use research grants funded through the NIH R01 grant mechanism. These groups were generated using a keyword search of an NIH-wide grants management database and subsequently screened by tobacco scientists to identify grants that matched the TTURC primary research subprojects on duration of the grant, timing of the funding period, type of research, and topical focus. The *longitudinal R01 (LR01) award comparison group* (N=21) was designed to match the 10-year duration and consistent institutional infrastructure and resources of the six TTURCs. The *stacked R01 (SR01) award comparison group* (N=39) was designed to match the duration and funding periods of the 39 TTURC subprojects. A more detailed description of the TTURC initiative and study design can be found in a previous publication [4].

UCSD base map of science

The UCSD Base Map of Science was computed based on 7.2 million publications and over 16,000 separate journals, proceedings, and series from Thomson Reuters' Web of Science and Elsevier's Scopus database over a five year period, 2001-2005 [1]. Bibliographic coupling using both highly-cited references and keywords was applied to determine the similarity of journals. Using a hierarchical, multi-step clustering procedure, journals were grouped into 554 clusters each representing a scientific paradigm (e.g., "Plant Physiology", "Finance", "Dietetics"). The 554 clusters (i.e. sub disciplines) were grouped into 13 major disciplines of science such as "Chemistry", "Medical Specialties", and "Humanities", which were color coded and labeled (Figures 1-3). Links on the map denote strong bibliographic coupling relations. Initially, the network was laid out on the surface of a sphere. To improve legibility, the spherical layout was flattened using a Mercator projection to give a two-dimensional version of the map that resembles a map of the world but with "continents" that represent difference scientific disciplines. A look-up table of what journals are contained in what (sub) disciplines is used to science-locate sets of publications.

Data and analysis

Publication data for the target group (TTURCs) and the two comparison groups (LR01 and SR01) were obtained from two NIH databases that link grant records to publication records in MEDLINE. The dataset of publications was overlaid onto the map by (fractional) matching of the journal names of the publications to the subdisciplines using the Sci2 Tool [19]. Most journals map to only one of the 554 subdisciplines. For example, *"Addiction"* is associated with the "Substance-abuse Treatment" subdiscipline, which is in turn a part of the "Medical Specialties" discipline. Some journals, however, map to many distinct subdisciplines. For example, *"Nature"* is associated with 77 sub disciplines, including "Vision", "Molecular Ecology", and "Climatology". For each association there is a match percentage. The three subdisciplines noted above have match percentages of 0.01282, 0.2564, and 0.01282 respectively; thus, one publication from *Nature* would add 0.01282 to the totals for the "Vision & Climatology" subdiscipline and 0.2564 to the total for the "Molecular Ecology" subdiscipline. In the science map data overlay, the final total for each subdiscipline is proportional to the area size of the circle. That is, subdisciplines with many fractionally associated journal publications are represented by large circles, while those with few publications are small. Nodes for subdisciplines with no publications are not drawn, though the links that make up the structure of the map remain visible.

RESULTS

Figures 1-3 depict the topical coverage of publications for the TTURC, LR01 and SR01 groups, respectively. The TTURC journal names match to the largest number of subdisciplines (n=267) in the map of science (Figure 1, Table 2), while the LR01 journal names match to 215 subdisciplines (Figure 2, Table 2), and the SR01 journal names match only 145 subdisciplines (Figure 3, Table 2). Ten journals (totaling 22 publications: 11 from the TTURC group, 5 from the LR01 group, and 6 from the SR01 group) could not be matched to nodes in the map of science and, as such, are not included in this visualization or the accompanying data tables.

Although the overlays for the TTURC, LR01 and SR01 publications show similar activations of subdisciplines, there are several interesting differences between groups when looking at the spread of topical coverage over time (Table 1; or click here for animations over time). Specifically, at the start of the initiative (1999-2002), the TTURC publications cover 7 out of the 13 disciplines, with nodes primarily falling within the "Health Professionals" and "Medical Specialties" disciplines. However, by 2005, the TTURC publications have spread across the map to all 13 disciplines of science. Moreover, between 2005 and 2009, while the nodes in the more distal disciplines remain static, there is a noticeable increase in activity and the size of the nodes in the "Health Professionals", "Brain Research", and "Medical Specialties" disciplines.

Similar to the TTURC group, the LR01 group (Table 1; or click here for animations over time) also initially covers 7 out of the 13 disciplines with the majority of nodes falling in the "Health Professionals" and "Medical Specialties" disciplines. However, despite an earlier start date (1994), the LR01 group does not begin to spread into more distal disciplines such as "Math & Physics" and "Chemical, Mechanical & Civil Engineering" until 2007, and never reaches the disciplines of "Humanities" and "Electrical Engineering & Computer Science". Moreover, the total activation of subdisciplines is only 80.5% of the activations of the TTURC group, (again) despite the earlier start date and the related opportunity to catch publications in fields that have

Table 1: Total Number of Disciplines Activated by Each Group over Time.

Group	1994-1999	1994-2002	1994-2005	1994-2007	1994-2009
TTURC	----	7	13	13	13
LR01*	7	8	8	11	11
SR01	----	4	9	11	11

*LR01 grants began in 1994.

Table 2: Total Number of Sub-disciplines Activated by Each Group over Time.

Group	1994-1999	1994-2002	1994-2005	1994-2007	1994-2009
TTURC	----	82	251	266	267
LR01*	111	137	141	215	215
SR01	----	16	85	145	145

*LR01 grants began in 1994

Abbreviations: TTURC: Transdisciplinary Tobacco Use Research Centers; LR01: Longtitudinal R01 Comparison Group; SR01: Stacked R01 Comparison Group

lengthier research and publication timelines. Similar to the TTURCs, the LR01 group does not show additional spread in the final years, but instead continues to contribute to disciplines that are already activated such as "Health Professionals" and "Brain Research".

Finally, despite a similar start date to the TTURC group, the SR01 group (Table 1; or click here for animations over time) initially covers only 4 out of the 13 disciplines with the majority of activity occurring in "Health Professionals" and "Brain Research". By 2007, this increases to 11 out of the 13 disciplines and publications begin to spread into more distal disciplines such as "Chemistry", "Electrical Engineering & Computer Science" and "Math & Physics". However, much like the LR01 group, activation in some of these more distal disciplines is much less pronounced than what is seen in the TTURC group. Furthermore, by 2009, two disciplines ("Humanities" and "Earth Science") remain unrepresented. Similar to the TTURC and LR01 group, the final two years show an increase in activation, but not in coverage, with the majority of the activity occurring in "Health Professionals" and "Brain Research".

DISCUSSION

Despite the increased investment in large-scale team-based research by government and private funding agencies, there has been little empirical research assessing the productivity and added-value of funding large center-based transdisciplinary research initiatives. This study begins to address this research question by using a novel visualization approach to assess topical coverage and spread of publications from a transdisciplinary center grant and two matched comparison groups.

With respect to the spread of topical coverage, the TTURC publications are represented in 7 out of the 13 disciplines within the first few years of the initiative, compared to 4 disciplines in the SR01 group and 7 disciplines in the LR01 group. This is interesting to note, because although the TTURCs ultimately produced more publications (n=579) than the LR01 (n=359) and SR01 (n=251) groups by the end of its ten-year funding period, the TTURCs actually displayed an initial lag in productivity

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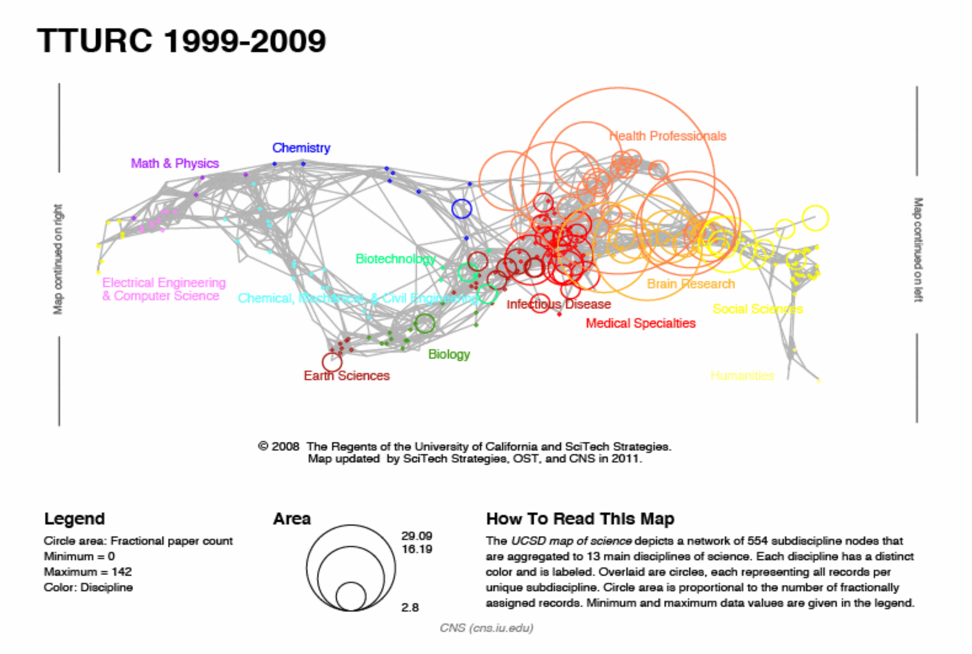

Figure 1 10-Year Topical Coverage of TTURC Publications on a Science Map.

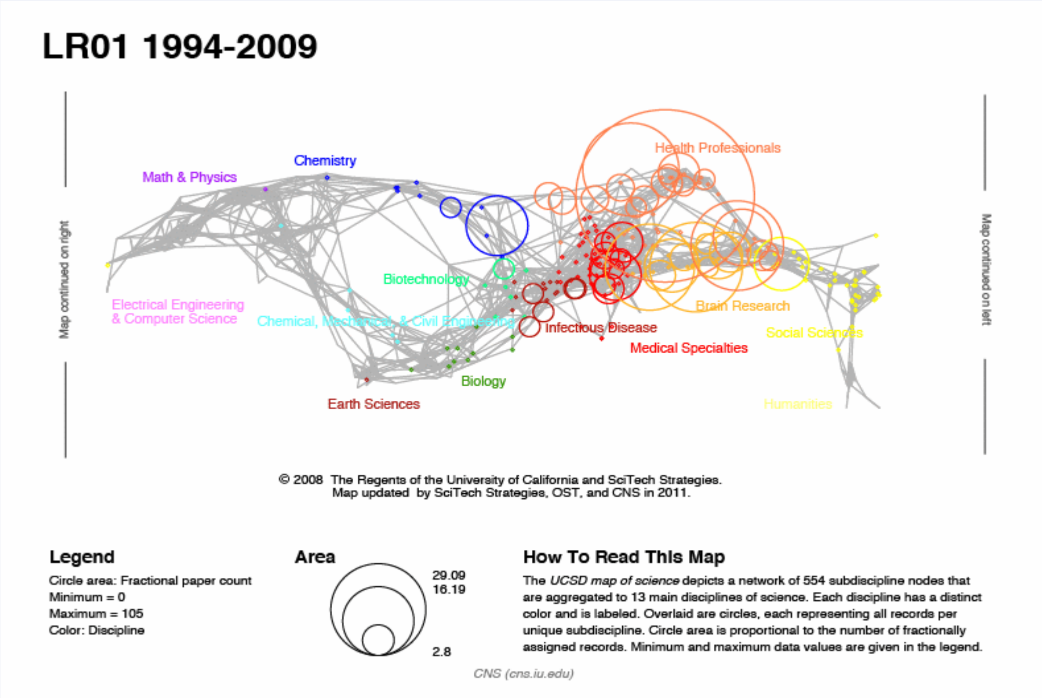

Figure 2 15 Year Topical Coverage of LR01 Publications on a Science Map.

compared to the other two groups, and did not begin to out-publish the R01 groups until year 5 of the initiative [4]. This suggests that although the TTURCs had fewer publications than the comparison groups at the start of the initiative, they were being published in journals that were more multidisciplinary in nature and therefore were able to spread to as many (i.e., LR01) or more (i.e., SR01) scientific disciplines.

When comparing the rate of topical coverage over time, by 2005 the TTURC publications have spread to each of the 13 scientific disciplines. In contrast, both the SR01 and the LR01 groups only reach 11 disciplines by the end of the ten-year period. This again suggests that the TTURC publications ultimately publish their findings in journals that have the potential to reach scientists across a wide range of research disciplines. While

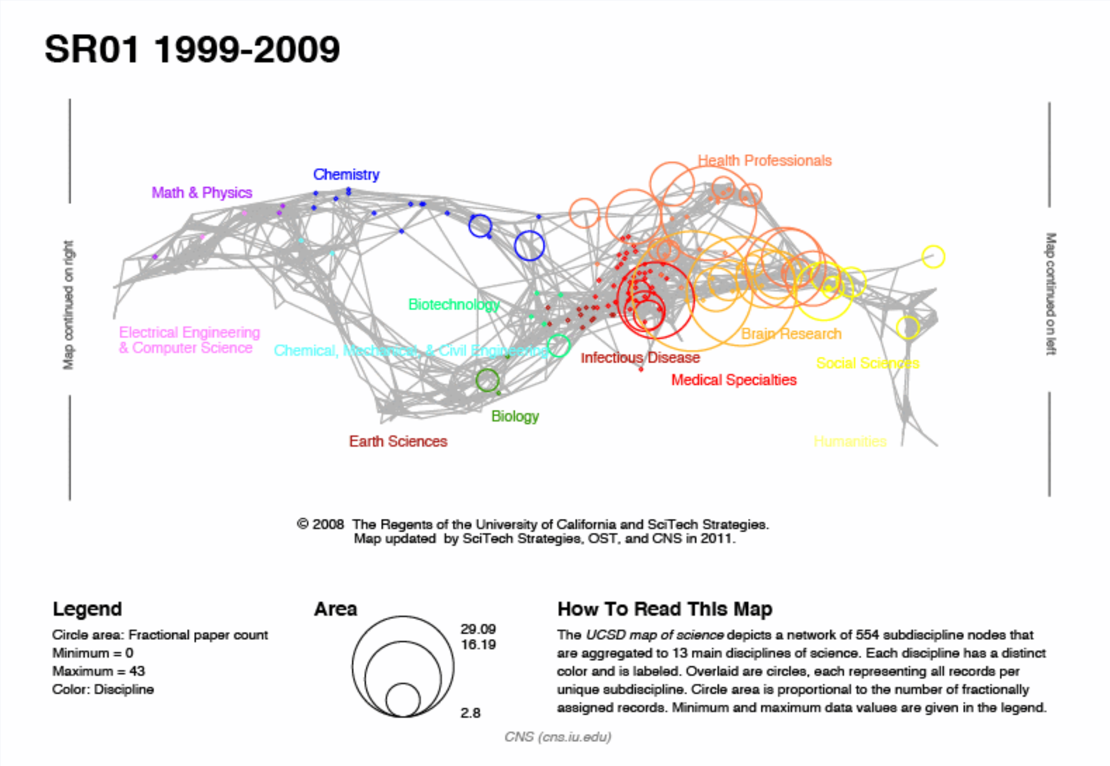

Figure 3 10-Year Topical Coverage of SR01 Publications on a Science Map.

publications in unidisciplinary journals might eventually be cited by additional distal disciplines over time, publishing research in journals that are more immediately accessible to scientists from multiple disciplines can accelerate the process by which these more distal domains learn about and build on new research findings.

In addition to examining the breadth of the research spread (i.e. # of subdisciplines activated) across the science map, this study also examined the depth of coverage (i.e. # of papers) within the disciplines represented in the map. For instance, all three groups tended to publish predominately in journals that fell under "Health Professionals", "Brain Research", and "Medical Specialties" disciplines. This finding is consistent with expectations given the topical focus of the research conducted by the three groups. Moreover, an analysis of the most frequently occurring journals suggests that all three groups are publishing a significant amount of their research in a core set of journals. However, it is notable that while "Health Professionals" is the most active discipline for the TTURC and LR01 groups, the SR01 group's most active discipline is "Brain Research". While there were no significant differences with respect to the types of research studies (i.e. laboratory, clinical, epidemiology, policy) which comprised each group [4], this finding was also evident when examining the most frequently occurring journals for each group. Specifically, the SR01 group published more frequently in journals such as *Neuropharmacology*, *Neuropsychopharmacology*, and *The Journal of Neuroscience*, compared to the TTURC and LR01 groups.

While this study represents an important first step in understanding the topical coverage and publication spread of a transdisciplinary center initiative over time, there are a number of limitations inherent in this methodological approach that must be acknowledged. Most generally, visualization techniques are helpful in identifying broad patterns and trends in large datasets. However, that macro-level view affords less sensitivity to small but possibly meaningful differences within and across groups. While there are science map interfaces that support zooming into lower levels and accessing and downloading publication details [20], the visualizations presented in this paper do not support interactive access to the micro-level data such as the subdisciplinary activations over time (Table 2) or additional publication information. In this study, the process for incorporating quantitative analyses was limited by the time and resources required to implement an online service that would provide this interactive access. In lieu of this interactive capacity, future reports generated by the Sci2 Tool [19,21] could be uploaded online and shared with relevant stakeholder groups to help further contextualize and interpret the findings.

Secondly, the UCSD Base Map of Science uses a "one to many" look-up table to assign journals to scientific (sub) disciplines. While the majority of journals are associated with exactly one (sub)discipline, there are a number of journals that are considered multidisciplinary in nature (e.g. *Science*), and therefore are associated with more than one (sub)discipline. As such, when a subdiscipline becomes activated in a more distal area of the map, it can be difficult to ascertain whether or not it is the result of a manuscript being published in a journal that is specific to that particular discipline, or simply one showing up in a journal that is linked to multiple subdisciplines. Although both interpretations imply that a publication is being disseminated to a diverse audience that reaches beyond its own subdiscipline, and thereby having the potential to spur new scientific innovation, the former is clearly more suggestive of the integration of a research area across subdisciplines that we expect to see from a transdisciplinary collaboration.

Finally, the accuracy of the visualizations used in this study is dependent upon having a comprehensive data set for each of the three groups. While a considerable amount of effort was spent on extracting and cleaning the publication data, there is always the potential for error. Specifically, this study relied on publications that directly cited the relevant TTURC or R01 grant numbers. Therefore, it is possible that some authors across all three groups failed to include this number and those publications were not captured. In addition, publication data were pulled using MEDLINE, and it is possible that some publications (e.g. those published in social science journals) were not included in our database. However, it is important to note that while these particular limitations may impact the raw numbers for all three groups, the strength of the visualization approach is its capacity to reveal larger trends and patterns that are not sensitive to small fluctuations in the data.

Despite some of these challenges, visualization approaches, especially when used in concert with other quantitative and qualitative methods, have the potential to yield important insights. For instance, the science mapping approach can provide information on trends in the number of publications per (sub) discipline (i.e. productivity) as well as the number and diversity of (sub)disciplines (i.e. multidisciplinarity) of publications that result from different types of funding mechanisms or team-based research collaborations. Additional bibliometic and network analyses can be conducted to understand which investigators are publishing in more interdisciplinary journals or in journals that represent more distal disciplines on the map, in an effort to characterize those investigators who are opening the doors for the diffusion of knowledge into other areas of research. In addition, network tools can enable us to understand major collaboration and diffusion pathways between subdisciplines [19, 22]. Future studies in this area should utilize these sophisticated new tools and methods to more fully understand and explicate the impact of different types of collaborations and funding mechanisms on the scientific landscape.

CONCLUSION

Scientific mapping techniques are helpful in providing a visual representation of large and oftentimes complicated datasets. They can serve as an important first step in understanding general publication patterns and can identify areas where a more detailed exploration of the data is warranted. This study utilized a scientific mapping approach to compare topical coverage and spread of publications from a large transdisciplinary center grant initiative (TTURCs) with two sets of matched investigator-initiated grants in the same field (tobacco use research). Findings revealed that the TTURC-initiated articles spread across the map of scientific publications more quickly and more comprehensively than the articles produced by both R01 comparison groups. These findings suggest that transdisciplinary research centers produce publications that are more rapidly disseminated across the scientific spectrum than publications stemming from more traditional unidisciplinary approaches. These findings are consistent with the notion that cross-disciplinary research has the capacity to speed the generation and dissemination of scholarly knowledge and, thereby, lead to important scientific innovations.

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